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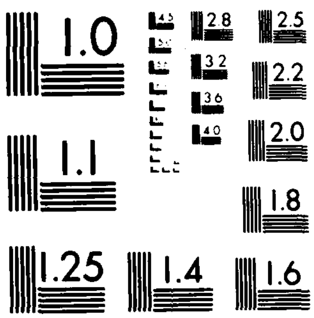

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November, 1983 SC5334.2SR

ADVANCED FILTER TECHNOLOGY

Summary Technical Report
For Period 08/01/82 through 09/16/83

Contract No. N00014-82-C-0725

Project No. NR 007-039 (240)

Prepared for:

Defense Advanced Research Projects Agency
Arlington, VA 22209

W.J. Gunning
Principal Investigator

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this program was to develop new concepts for narrowband wide field-of-view filters for submarine laser communications (SLC). Initial modeling work was performed on several promising birefringent filter designs and a brief study of the low temperature properties of sheet polarizers was performed. An extension of the concept of the magneto-optic filter has been derived which results in lower magnetic field requirements.

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Following a redirection of program goals, the assembly of wide field-of-view half waveplates, as required by the cadmium sulfide dispersive birefringent filter for submarine laser communications, was pursued.

SUMMARY REPORT

The goal of this program was to develop a spectral filter technology which could address short wavelength submarine laser communications. This filter was to have a narrow bandwidth and wide field-of-view. The original tasks of this program were:

1. Experimental Filter Development:

   a. Extension of the cadmium sulfide (CdS) dispersive birefringent filter (DBF) technology to shorter wavelengths through the use of alternate materials or by operating a CdS filter at cryogenic temperatures.

   b. A demonstration of advanced birefringent filter concepts not requiring anomalous properties of optical materials.

2. Study of alternate approaches to narrowband wide field-of-view filters including:

   a. Liquid crystal filter
   b. Magneto-optic filter
   c. Gyro-tropic filter
   d. Christiansen-Bragg filter
   e. Saturable absorbers
   f. Atomic resonance filters

3. A study to investigate the properties of various polarizers at short wavelengths in the visible, since most filter approaches outlined in the program require polarizers.

A small amount of work had been performed on these tasks when the program was reduced in size and redirected to support the DARPA/NAVELEX Submarine Laser Communication Receiver/1B (SCLR/1B) program (Contract No. N00039-82-C-0160) for which 55 CdS dispersive birefringent filters were to be fabricated. The effort was now to support work in the study and fabrication of wide field half-waveplates which are required as part of the wide field structure of the DBF. Also included was support of the filter assembly effort related to the selection of filter elements, including the above mentioned waveplates.

This report describes the results obtained under the original program tasks and the nature of the work performed following the redirection.

Task 1 Experimental Filter Development

a) Short Wavelength Birefringent Filters

The dispersive birefringent filter which is being fabricated for the SLCR/1B program uses CdS as the birefringent waveplate material (Fig. 1).[1-4] Its unparalleled properties of simultaneous narrow bandwidth and large field-of-view are the result of the large dispersion of the birefringence of CdS. Unfortunately, this approach cannot be extended into the blue region of the spectrum because of the optical absorption edge of the CdS. One possibility was to cool the filter, thereby shifting the bandedge to shorter wavelengths.[5] Figure 2 shows the spectral transmission of CdS at room temperature and at 80K. The data indicate that operation at 503 nm may indeed be possible, thus matching the wavelength of the HgBr laser. Other measurements of the birefringence and its dispersion (Figs. 3 and 4) show that equivalent performance to that of the room temperature device at 5320Å might be expected. These results were obtained prior to the program, but the issue of polarizers which might operate at these wavelengths and at reduced temperature had to be addressed.

A critical component in all birefringent filters is the polarizer. Specially treated polyvinyl alcohol polarizers were developed for the CdS DBF

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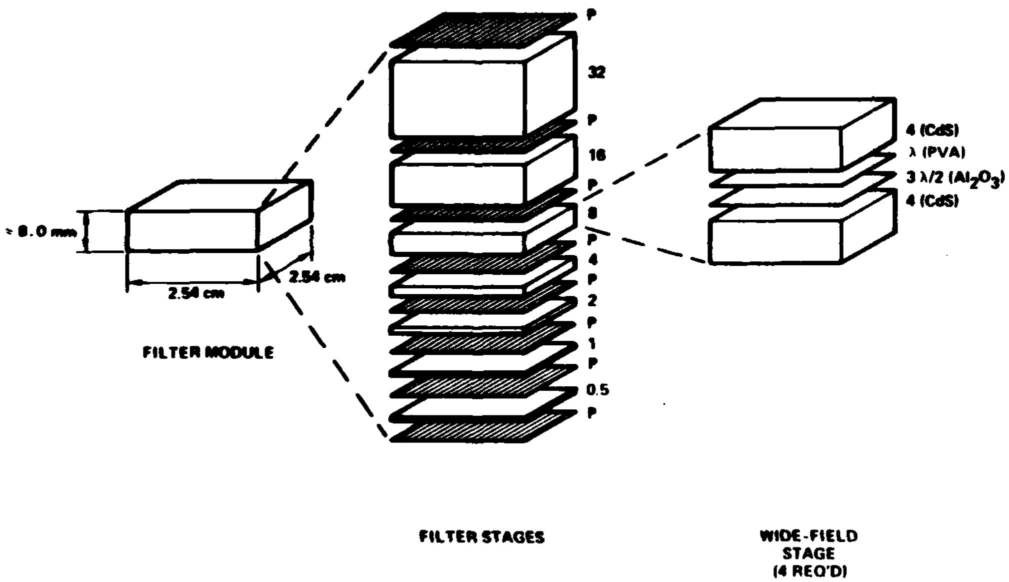

FILTER STAGES

INTERFERENCE ORDER	CdS PLATE THICKNESSES (mm)	WIDE-FIELD?
32	1.16 (2)	YES
16	0.58 (2)	YES
8	0.29 (2)	YES
4	0.145 (2)	YES
2	0.145	NO
1	0.0725	NO
0.5	0.0362	NO

POLARIZERS (8)

SPECIALLY TREATED HN-38 POLARIZER
THICKNESS 0.025 mm

WAVEPLATES (4)

COMPOUND WIDE-FIELD HALF WAVEPLATE
POLYVINYL ALCOHOL – FULL WAVE t 0.1 mm
SAPPHIRE – 3/2 WAVE t 0.1 mm

Fig. 1 Expanded view of CdS dispersive birefringent filter.

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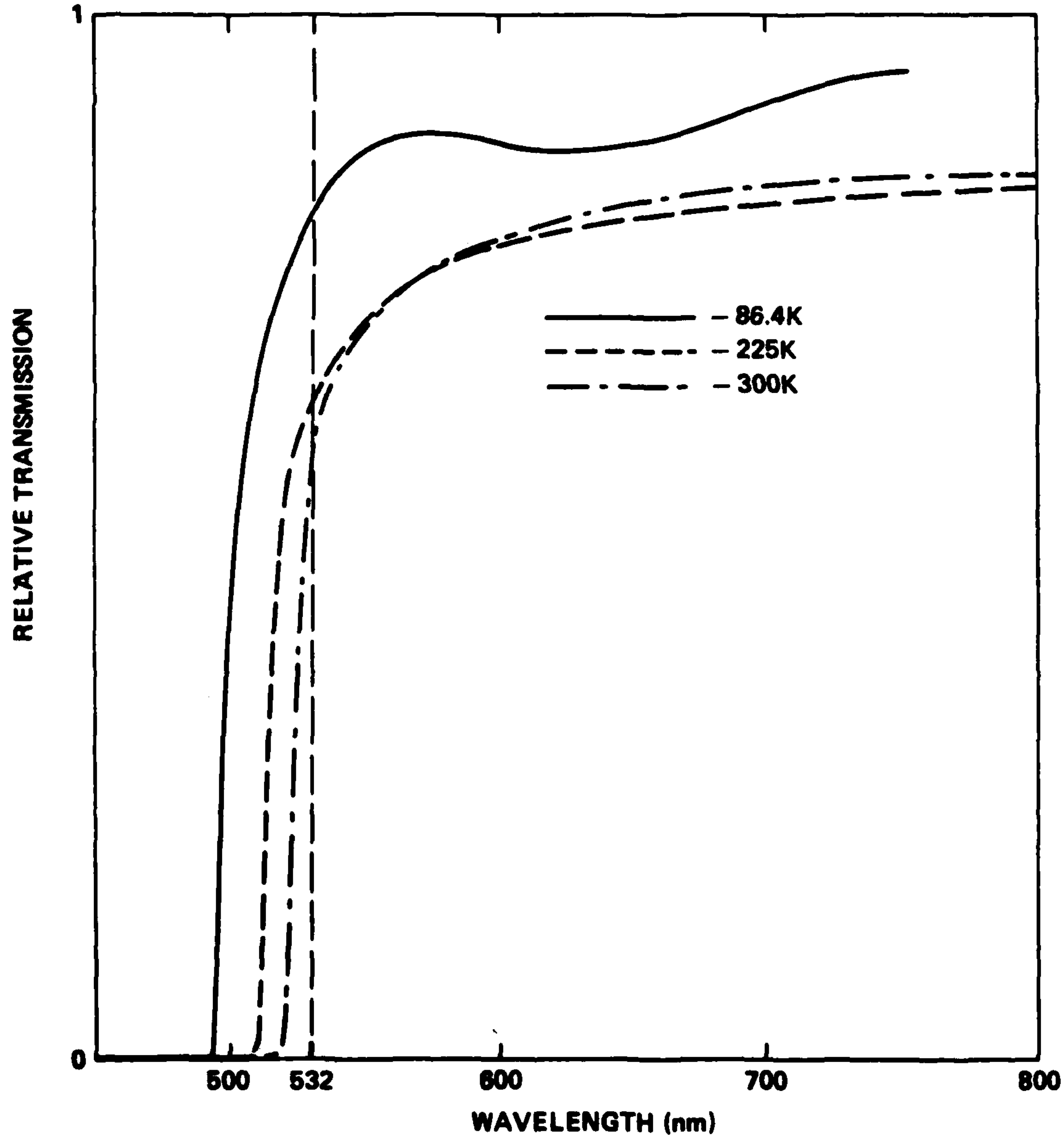

Fig. 2 Spectral transmission of CdS at various temperatures.

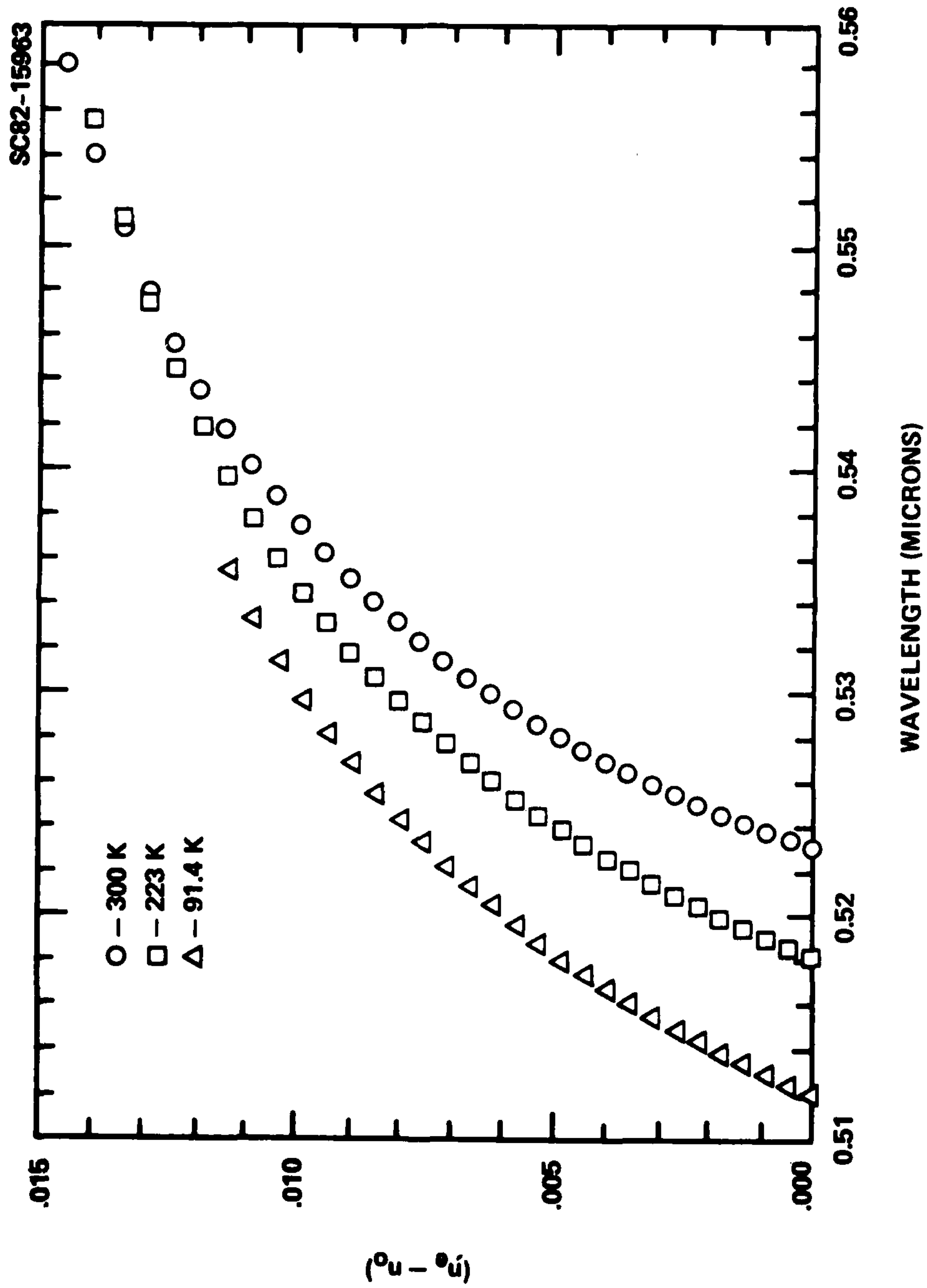

Fig. 3 Birefringence of CdS at several temperatures.

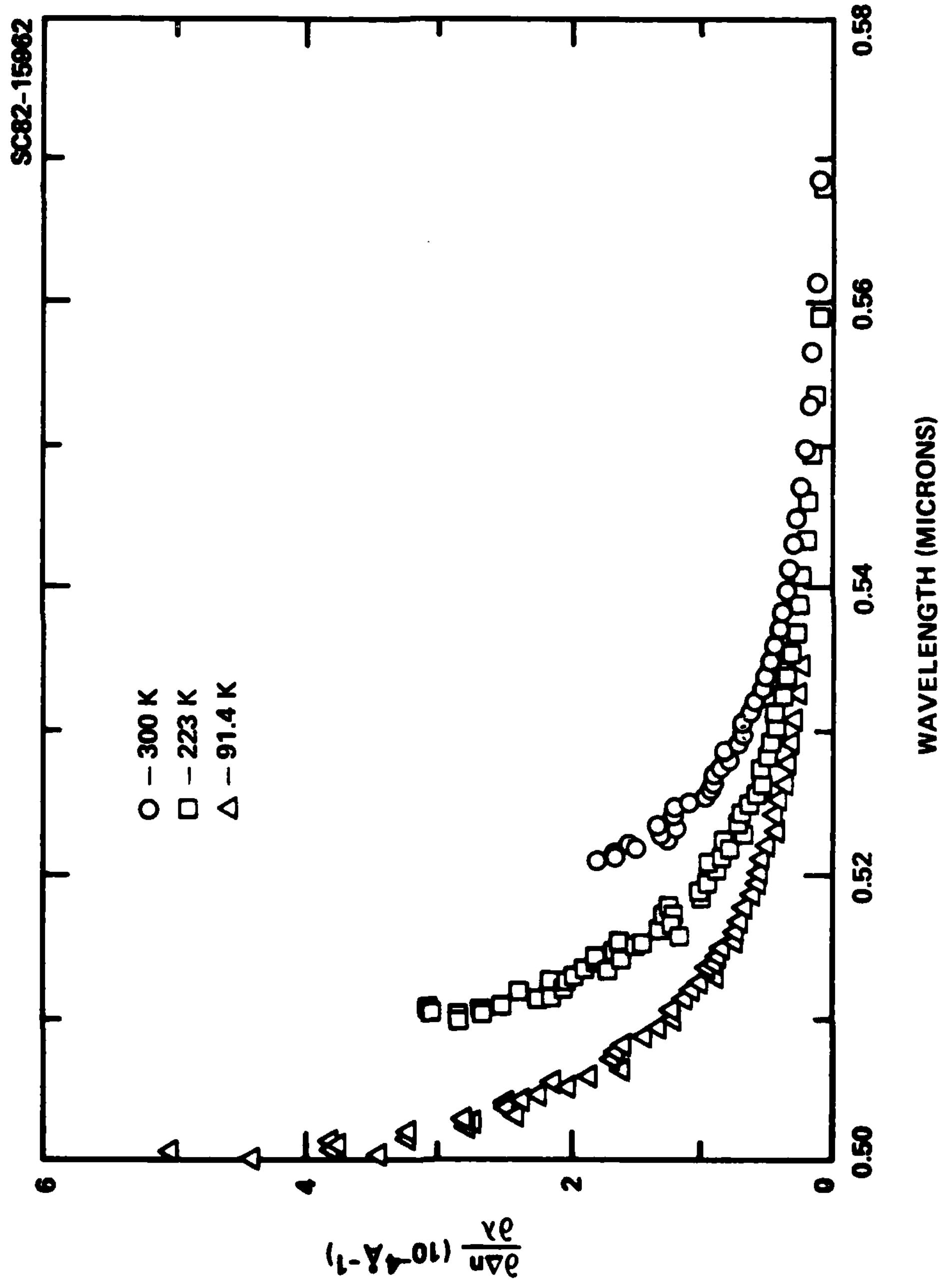

Fig. 4 Birefringence dispersion of CdS at several temperatures.

in order to achieve high transmission and maintain good extinction.[6] These polarizers had the disadvantage of showing degraded extinction for wavelengths shorter than 5300A. This presented no problem since the CdS bulk absorption effectively blocked the short wavelength side of the filter. This, however, would be a significant problem for shorter wavelength operation. In order to determine how these polarizers might behave at cryogenic temperatures, both virgin and treated polarizers were measured at liquid nitrogen temperature with the following results. As seen in Figs. 5-8, as the temperature was lowered, the transmission for the parallel polarization decreased and the extinction simultaneously degraded. It was clear that this class of polarizers would not be suitable for low temperature operation.

Other polarizers were investigated as well. PVA-iodine polarizers from American Hoechst Corporation were evaluated which seemed to exhibit somewhat better short wavelength performance than the virgin Polaroid material. However, a complete assessment was not made. In addition, reduced silver halide glass polarizers from Corning were tested (Fig. 9).[7] While showing some promise, these samples were not optimized for these wavelengths of operation.

The other approach to shorter wavelength operation of DBF technology, was to investigate the use of alternate dispersive birefringent materials.[8] A favorable choice is the material $Zn_xCd_{1-x}S$.[9,10] This solid solution is optically quite similar to CdS, but the bandedge and its region of strong dispersion are shifted to shorter wavelengths in proportion to the concentration of zinc. While a few test samples were available for measurements of their optical properties prior to the program (Figs. 10-12), the problem of growing material without a compositional gradient was not solved. Since then, a new approach to the growth of this material has been suggested, but has not yet been attempted.

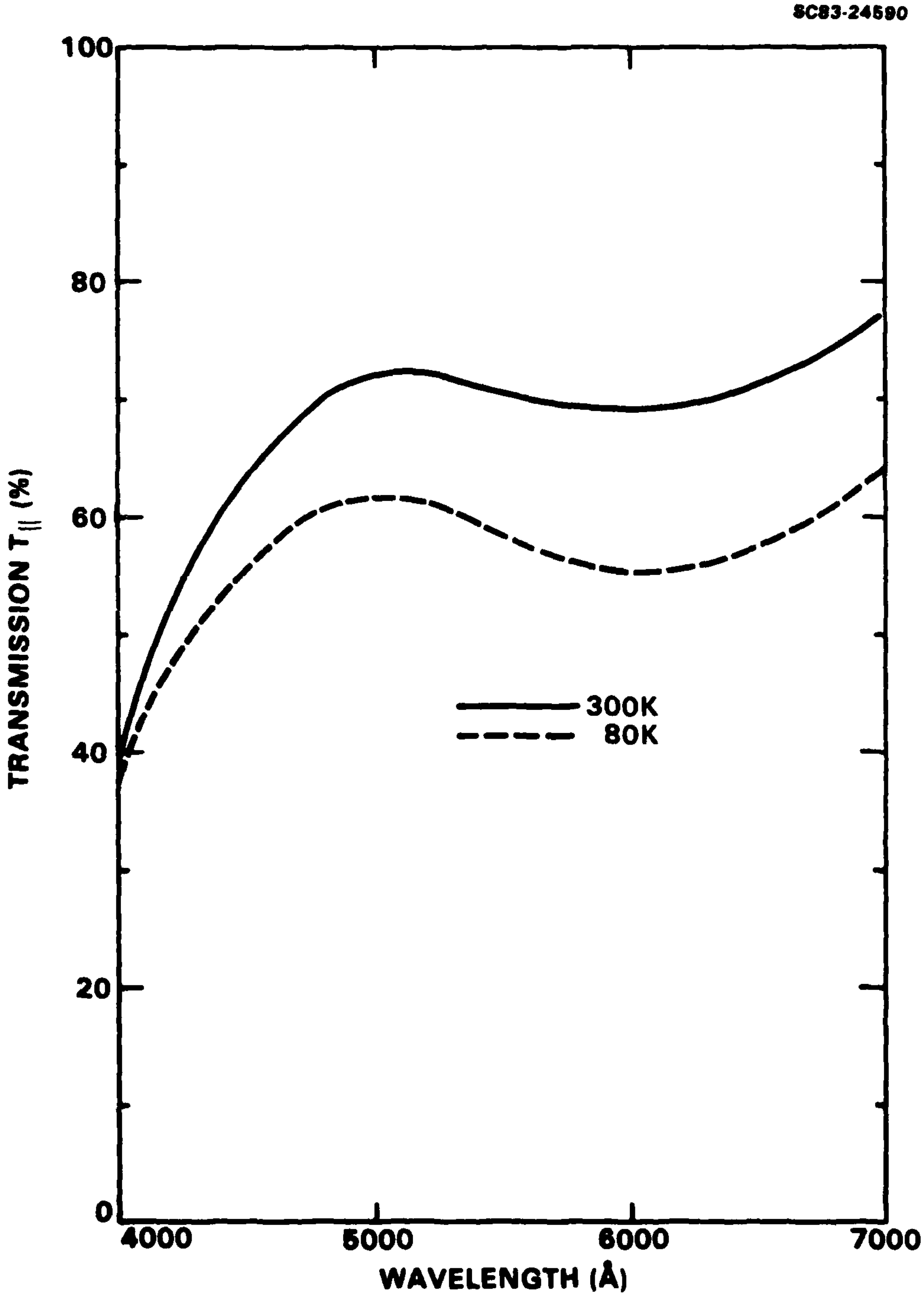

Fig. 5 Transmission (parallel) of HN-38 polarizer at 300K and 80K.

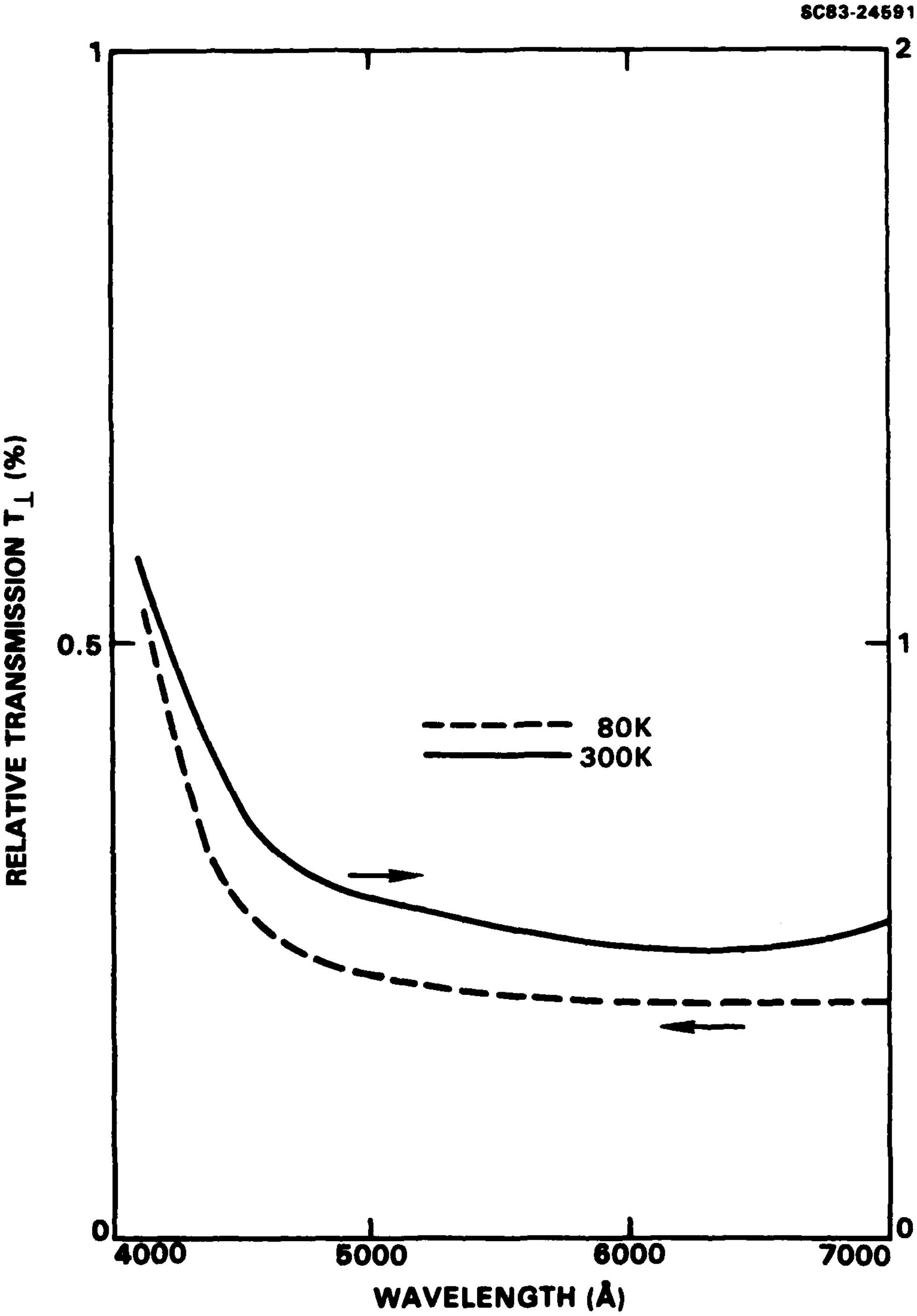

Fig. 6 Transmission (crossed) of HN-38 polarizer at 300K and 80K.

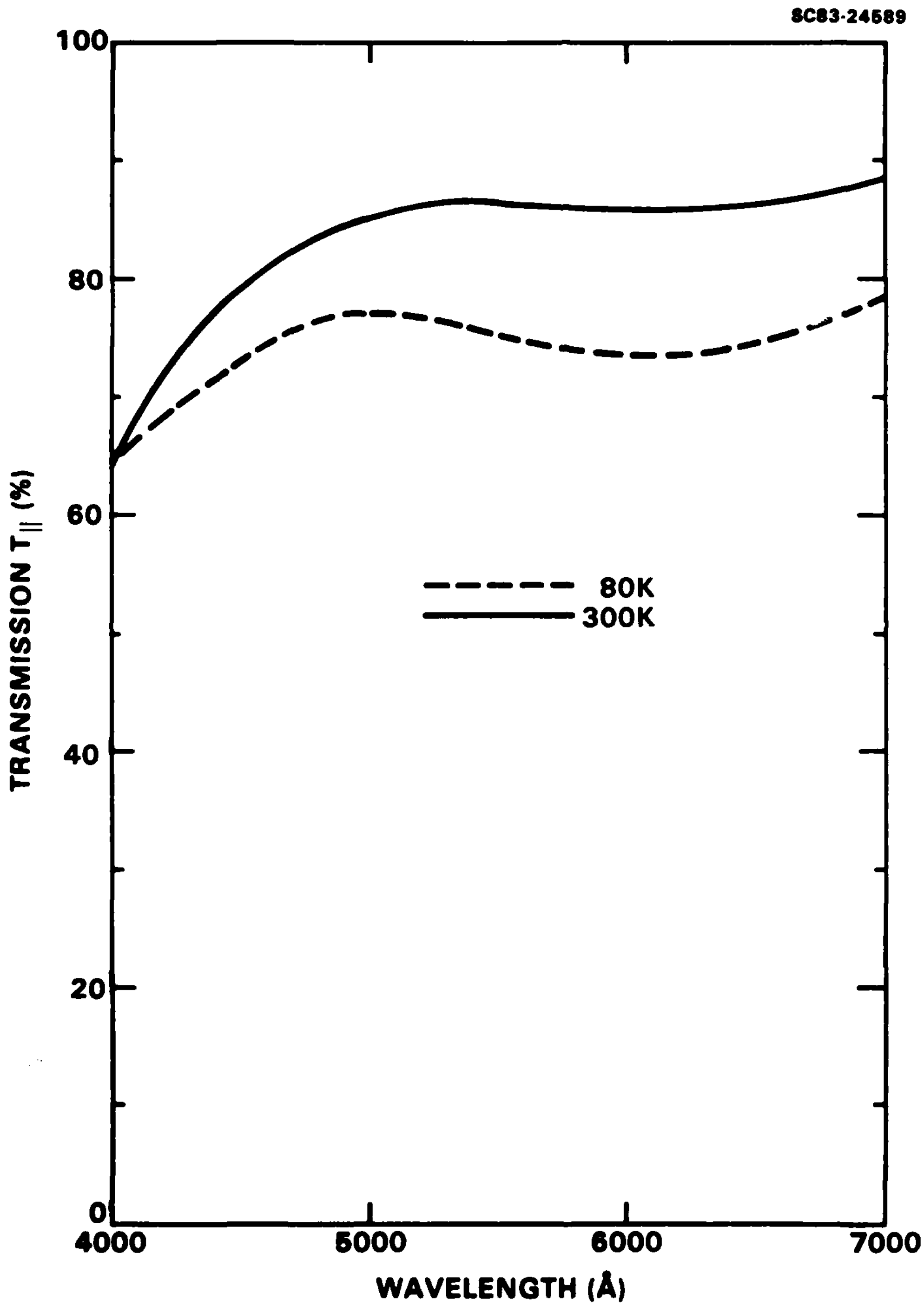

Fig. 7 Transmission (parallel) of high transmission polarizer at 300K and 80K.

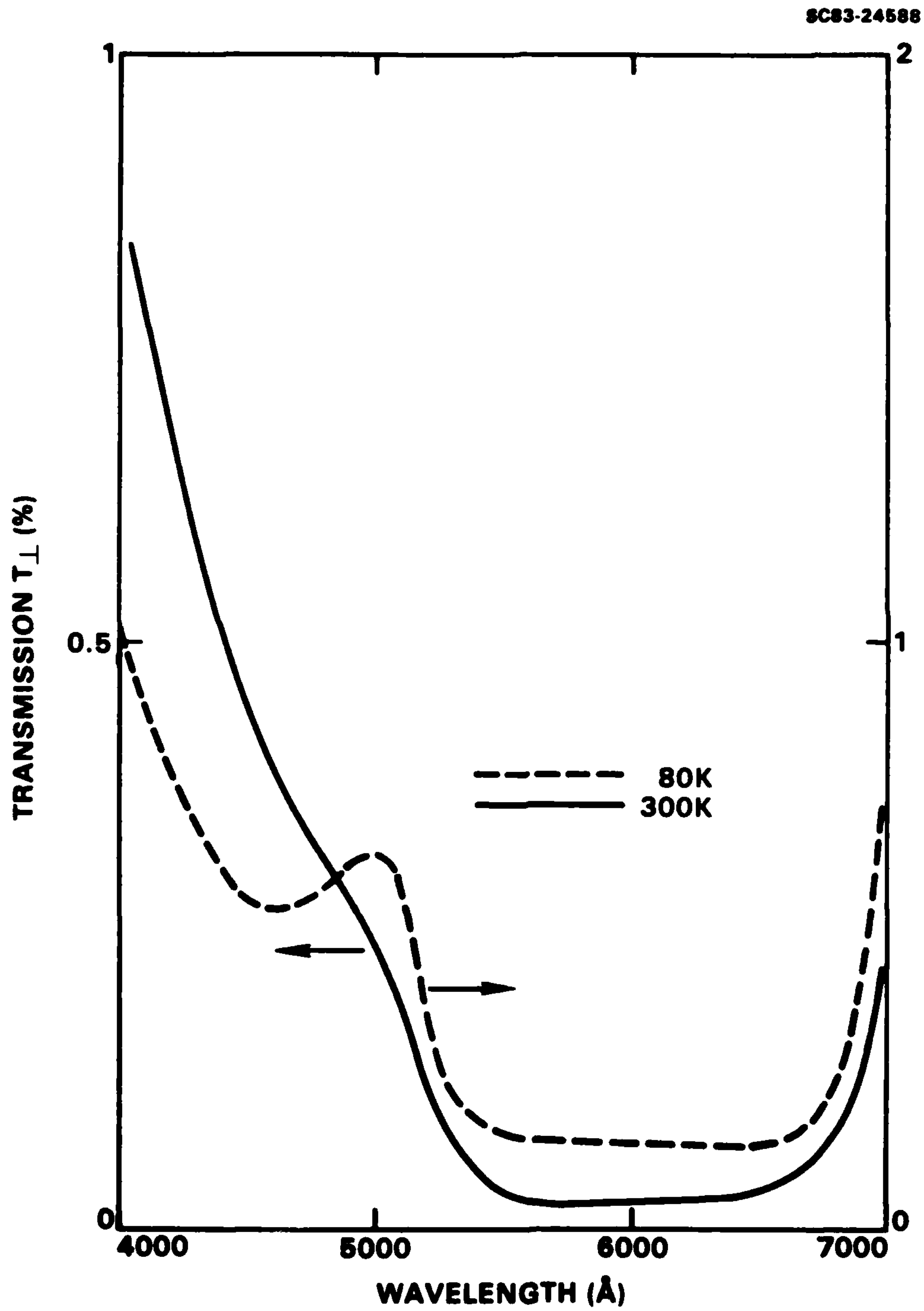

Fig. 8 Transmission (crossed) of high transmission polarizer at 300K and 80K.

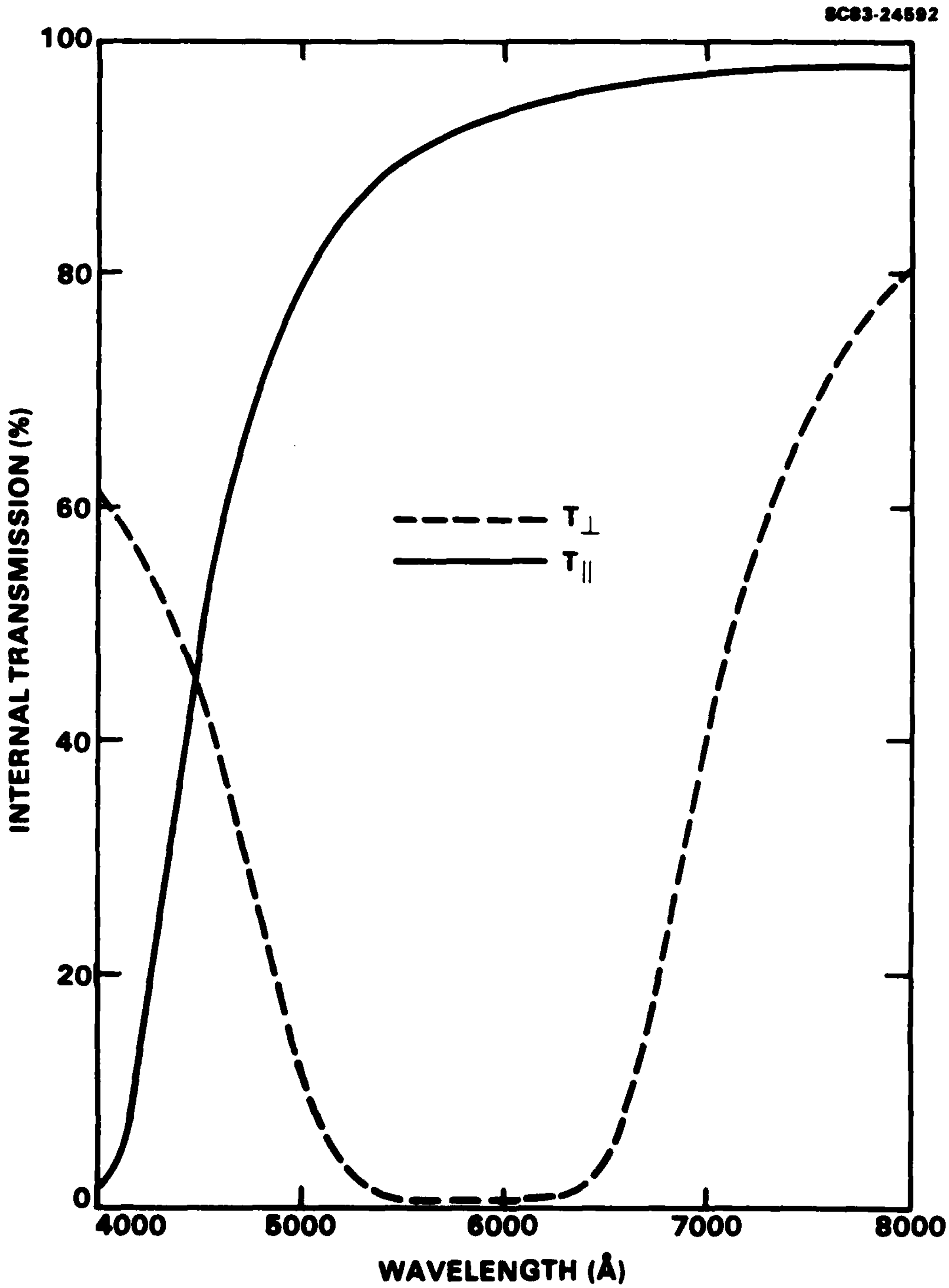

Fig. 9 Transmission properties of reduced silver halide glass polarizers.

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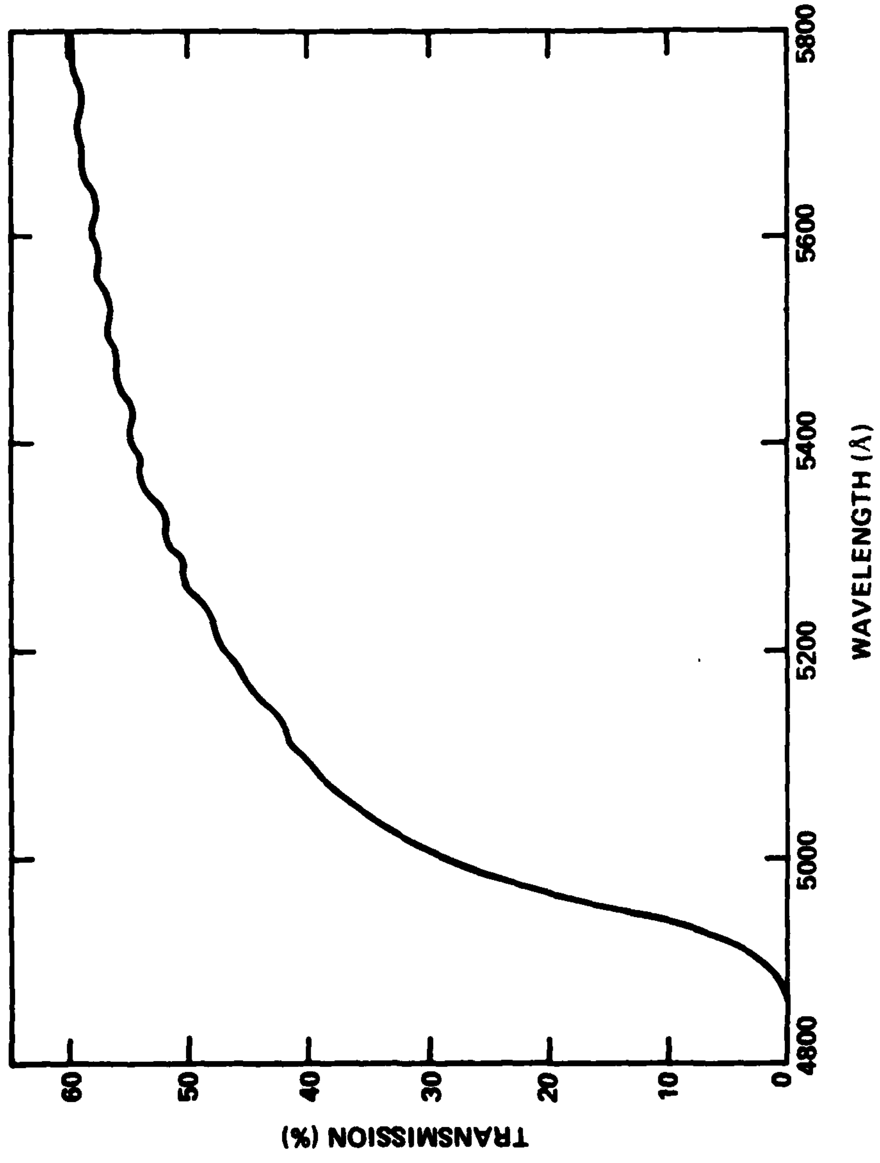

Fig. 10 Spectral transmission of $Zn_{.1}Cd_{.9}S$.

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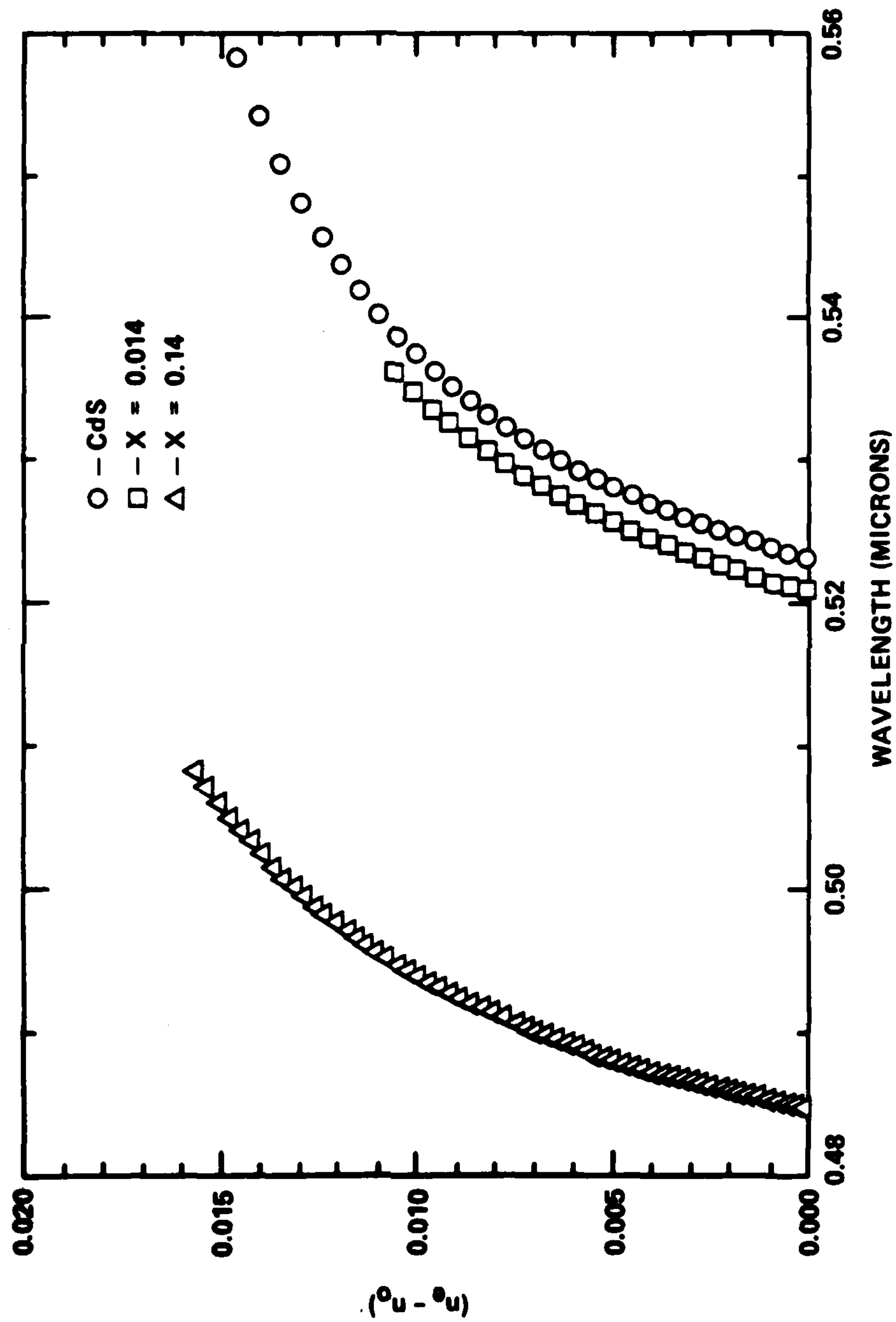

Fig. 11 Birefringence of $Zn_xCd_{1-x}S$.

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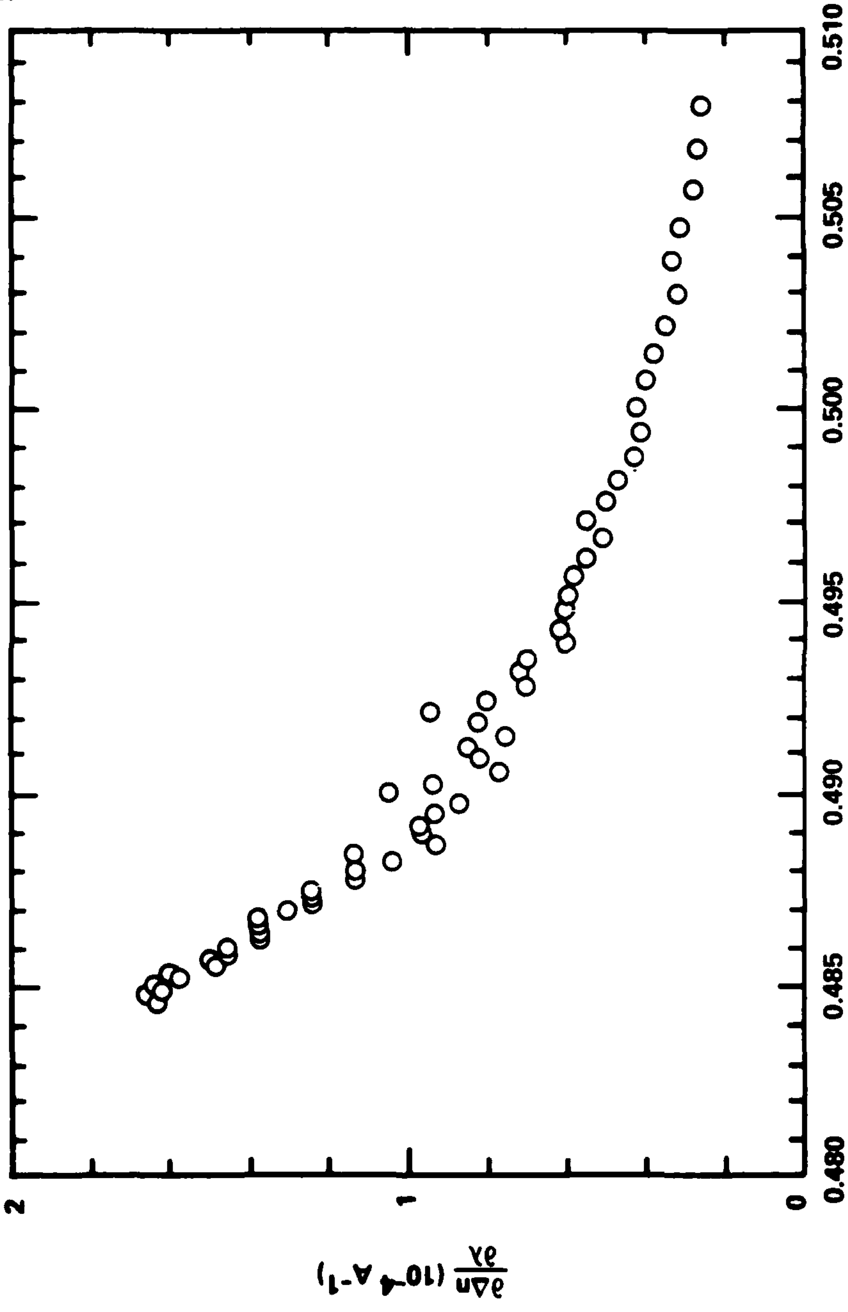

Fig. 12 Birefringence dispersion of $Zn_{0.14}Cd_{0.86}S$.

b) Advanced Birefringent Filter Designs

This effort was to consist of demonstrating several new wide field-of-view geometries which could be made in compact structures. In his pioneering work, Lyot suggested three wide field geometries, shown in Fig. 13, each of which produces a moderately wide angular aperture.[11] However, use of common materials such as quartz still results in a significant thickness to the overall filter. Three new designs have been suggested which provide greater fields-of-view for equivalent bandwiths while still maintaining a rather thin filter overall. These designs are illustrated in Fig. 14. An effort was made to demonstrate the validity of the "Lyot-2x" geometry using TiO_2 and $LiNbO_3$. While this was progressing favorably, the final demonstration was not performed, since additional optical fabrication work was required at the time at which the program was redirected.

Task 2 Alternate Filter Concepts

The dispersive magneto-optic filter was suggested by Yeh[12] as an approach to a very narrowband wide field-of-view filter for blue/green signal detection. Resonance enhanced Faraday rotation in an atomic vapor rotates the plane of polarization for photons which interact with the vapor. Crossed linear polarizers on either side of the vapor cell provide the selection against the out-of-band photons. High throughput is achieved by appropriate selection of the optical thickness of the vapor cell and the magnitude of the applied magnetic field.

Additional studies of the magneto-optic fiter resulted in the realization that the magnetic field required for high throughput could be significantly reduced (to 100 Gauss) by operation at a wavelength slightly displaced from the actual atomic resonance.[12] The effect would be enhanced by the dispersion of the atomic resonance.

This approach has the disadvantage that polarizers are required, thereby causing a limitation in the field-of-view and placing a polarizer determined limitation on the out-of-band extinction. However, the great

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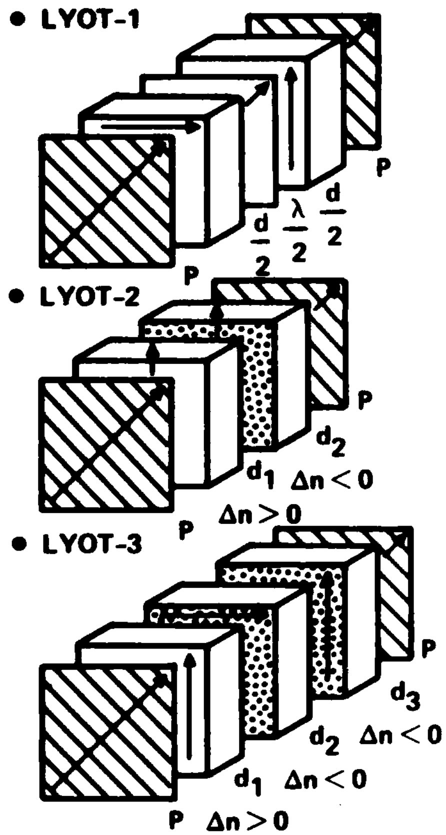
- ORIGINAL CONFIGURATIONS INVENTED BY LYOT



MATERIAL	Δ-$\lambda_{1/2}$ @ 5000Å	FOV	THICKNESS (THICKEST STAGE)
$PbMoO_4$	1Å	± 23°	2.9 mm
TeO_2 $PbMoO_4$	1Å	± 13°	10.88 mm
TiO_2 $LiNbO_3$	1Å	± 30°	6.62 mm
$PbMoO_4$ TeO_2	1Å	± 20°	3.49 mm

Fig. 13 Traditional wide field-of-view birefringent filter geometries.

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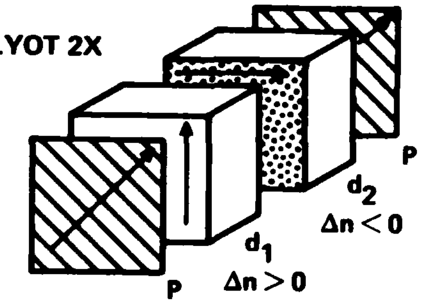
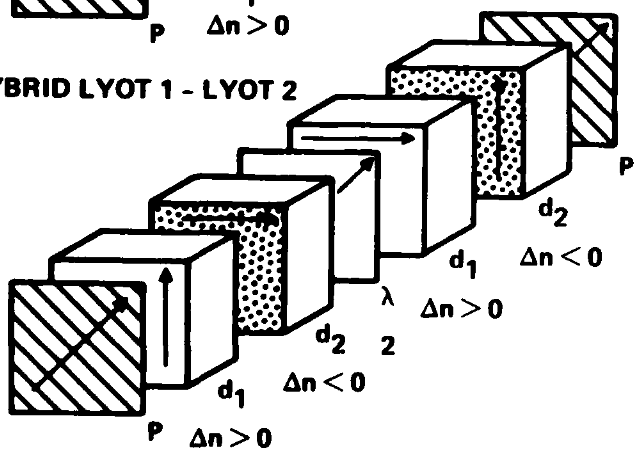
- "DISPERSIVE" LYOT-3
  - LARGE | Δn | IN THIS AND OTHER FILTERS DESCRIBED HERE IS MORE IMPORTANT THAN MAGNITUDE OF $\frac{\partial \Delta n}{\partial \lambda}$
- LYOT 2X



- HYBRID LYOT 1 - LYOT 2



MATERIAL	$\Delta\text{-}\lambda_{1/2}$ @ 5000Å	FOV	THICKNESS (THICKEST STAGE)
TiO_2 $PbMoO_4$	1	± 30°	2.9 mm
TiO_2 $LiNbO_3$	1	± 45°	4.17 mm
$PbMoO_4$ TeO_2	1	7 ± 40°	3.3 mm
$LiNbO_3$ TeO_2	1	7 ± 40°	6.6 mm

Fig. 14 Advanced wide field-of-view birefringent filter geometries.

advantage of the magneto-optic filter approach is that detection of the signal occurs at the signal frequency and not at a displaced wavelength as in the atomic resonance absorption filter (ARAF).[13] In that filter, the blue photon is absorbed and a near-infrared photon is emitted. Detection at this wavelength is difficult because low noise, high gain, room temperature detectors are not commercially available.

Task 3 Polarizer Study

As part of the development program for the CdS dispersive birefringent filter, high transmission polarizers were developed.[6] This was accomplished because of the unacceptable loss that would have otherwise been encountered in the eight polarizer structures. Polaroid HN-38 polarizers were treated in a humidity oven to increase the internal transmission of the parallel component while the extinction properties were carefully monitored so that the out-of-band rejection of the filter would not be impaired. An empirical study determined the optimum conditions for the heat treatment, and resulted in polarizers with an internal transmission at 5320Å of 95% for parallel polarization and less than 0.3% for the crossed polarization. The extinction remained high for longer wavelengths, but was severely degraded for wavelengths shorter than about 5250Å (Fig. 15). For this reason, it was necessary to investigate other polarizers for short wavelength operation.

An extensive study in this area was not undertaken, as mentioned under Task 1. However, the American Hoechst polarizers and the Corning silver/glass polarizers do show promise in this area.

Support of SLCR/1B Program

The remainder of the activities under this program were in the area of supporting the fabrication of CdS DBFs for the SLCR/1B program. The principal activity supported by this program was the actual fabrication of wide field-of-view half-waveplates which are incorporated into the Lyot-1 wide field stages of the filter, as seen in Fig. 1. The field-of-view of the CdS

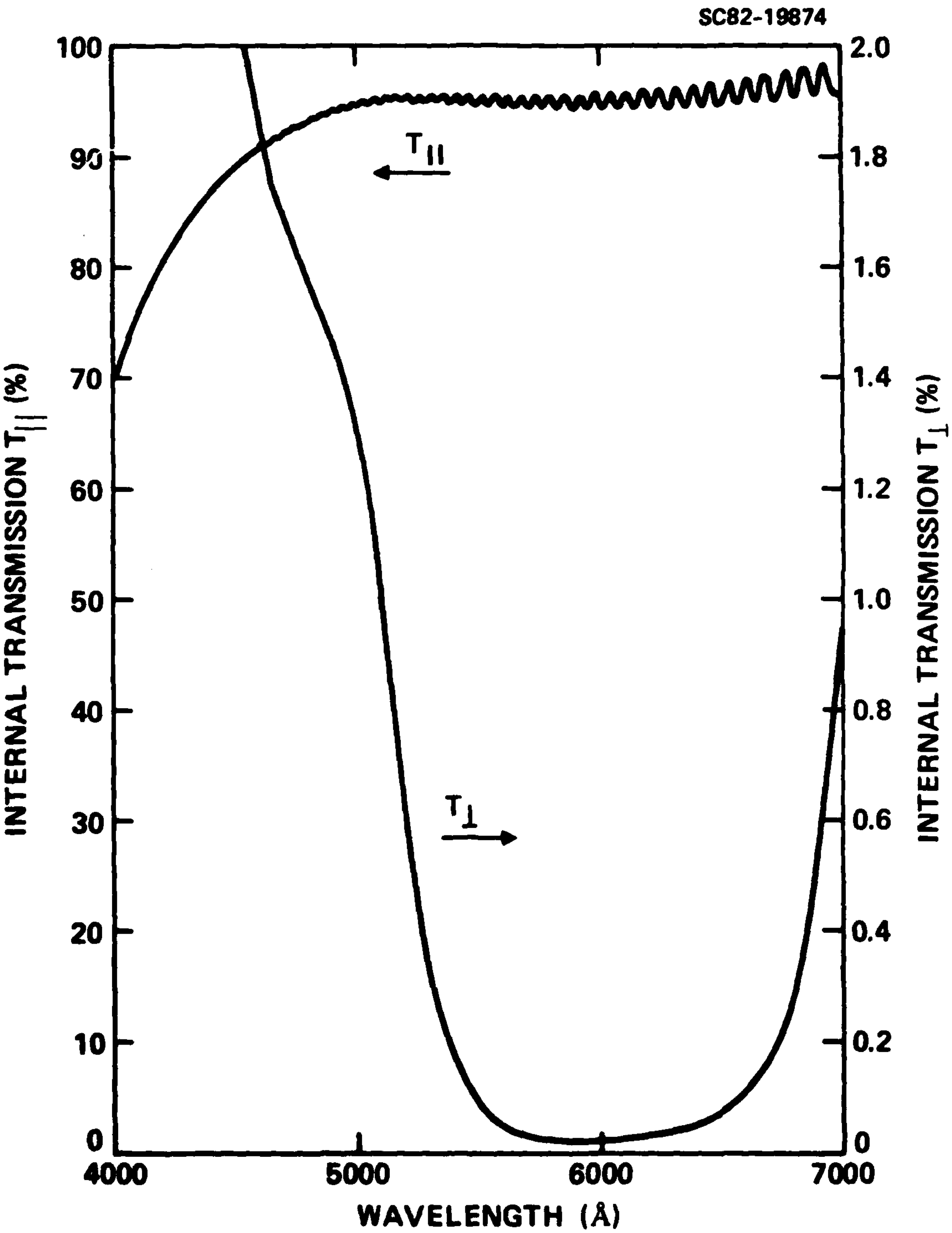


Fig. 15 Transmission properties of specially treated HN-38 polarizer.

DBF is so large that simple half-waveplates do not have adequate wide field response to accommodate it, hence the need for compound waveplates.

The compound waveplates are composed of a 3/2 wave sapphire waveplate and a full waveplate of stretched polyvinyl alcohol (PVA) assembled in the Lyot-2 geometry. The sapphire was provided by Crystal Systems and fabrication was initially performed by Kappler Crystal Optics. When this arrangement did not work out, fabrication was transitioned to Rockwell's Autonetics Marine Systems Division as part of the overall technology transfer of the filter fabrication processes. The PVA was provided by Polaroid Corporation and is laminated to a thick film of cellulose acetate butyrate to provide environmental protection. This film was dissolved off using methyl ethyl ketone with a methyl cellosolve wash. When unsupported, this material is rather susceptible to increases in temperature. The retardation is observed to decrease rapidly upon exposure to temperatures only slightly above room temperature. This presented a slight storage problem, but fortunately, when bonded to other filter components, this extreme reaction disappeared. Apparently, the stretched material relaxes when heated in its unsupported state. No problems have been observed in assembled waveplates or completed filters.

A simple algorithm was employed to assist in matching of the PVA and sapphire parts to achieve half-wave retardation at 5320Å. This allowed for some error in the thickness (retardation) of the individual elements. Each selection was confirmed by performing a spectral scan of the combination between crossed polarizers. These parts were then carefully aligned on a precision polarization stage and cemented with Epo-Tek 301 optical cement. It was found that some assembled parts had significant errors because of slight errors in the selection process, and because of temperature effects on the unsupported PVA during bonding and subsequent deblocking of the parts from their glass support. A soak in 50% acetic acid was found to dissolve both the PVA and the epoxy and allow reuse of the sapphire plate.

Other filter assembly procedures were also supported by the ramaining funding of this program.

Considerations for Future Filter Research

The decision to redirect the funding of this program to support the SLCR/1B effort was a reasonable one considering the need to achieve a favorable demonstration of the technology under the SLCR/1B program. This infusion of support was important in allowing the filter fabrication effort to continue.

It is unfortunate that the research in the new filter designs which the program was to address could not be performed. The successful demonstration of the Cds ARAF has supplanted the need for birefringent filters for short wavelength SLC. However, other visible sensors would benefit from birefringent filters or other filter designs which do not require continuous consumption of power to heat them above ambient. In addition, these filters are capable of imaging, making them useful for certain applications where resonance absorption filters would fail. Perhaps these issues can be addressed in the future as these other applications become better defined, and the need again arises for advanced filter concepts.

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